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The Enhanced Airborne Measurement Facility Recording System

S.I. Altman
P.M. Daly

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Lincoln Laboratory
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16. Abstract

The Airborne Measurement Facility (AMF) is a data collection system that receives and records pulse and other information on the 1030/1090-MHz frequencies used by the FAA's secondary surveillance radar and collision avoidance systems. These systems include the Air Traffic Control Radar Beacon System (ATCRBS), the Mode Select (Mode S) Beacon System, and the Traffic Alert and Collision Avoidance System (TCAS). Designed and constructed by MIT Lincoln Laboratory in the 1970s, this unique measurement tool has been used to conduct advanced research in beacon-based air traffic control (ATC) over the past 20 years.

The original AMF included a recorder capable of recording at the maximum rate of 2 Mbits/sec. Although this recording system worked well, it had become difficult to maintain in recent years. In 1993, the Air Traffic Surveillance Group, with support from the FAA, decided to incorporate the latest tape recording technology into an enhanced AMF recording system.

The main purpose of this report is to document the design details of the enhanced AMF recording system. A second purpose is to provide guidance to analysts for AMF operation and data analysis. Finally, this report complements an AMF User's Manual, which is a more detailed document for using and maintaining the AMF.

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1. INTRODUCTION

In 1975, MIT Lincoln Laboratory developed the Airborne Measurement Facility (AMF) to detect and record pulsed signals in the 1030 MHz and 1090 MHz bands. These are the frequencies used by the Federal Aviation Administration (FAA) for secondary radar surveillance of beacon-equipped aircraft. Since that time, the AMF has been used for many purposes, including air-to-air data collection during the development of the Traffic Alert and Collision Avoidance System (TCAS) and ground-based measurements for assessing the airport surface environment.

Because of the high data rate, the original AMF included a recorder capable of recording at the maximum rate of 2 Mbits/sec, but only for about 15 minutes and 44 seconds (944 seconds). This original recorder was an instrumentation-type tape recorder that used large, cumbersome tapes of a non-standard format that held 1.888 Gbits of data. To convert the instrumentation tapes to a readable form, an independent ground-based system was required. Refer to Reference [1] for a full description of the original AMF system. Although this recording system worked well, it had become difficult to maintain in recent years.

In 1993, the Air Traffic Surveillance Group decided to incorporate the latest tape recording technology into an enhanced AMF recording system. The AMF refurbishment takes advantage of 8-mm tape drives that are smaller and more reliable, can hold much more data, support higher recording speeds, and are easier to use than the original AMF recorder. The new recording system offers extensive monitoring information, complete software control, and has full playback capabilities eliminating the original AMF ground system. Not only has the data extraction process been reduced from several weeks to several minutes, but continuous recordings for up to 5 hours and 53 minutes at the peak data rate of 2 Mbits/sec can be made, totaling 42.4 Gbits of data. The recording system can record additional data along with the original beacon AMF data: aircraft position data from a Global Positioning Satellite (GPS) unit; altitude data from an encoding altimeter; and data from an on-ship Mode S transponder.

2. AMF OVERVIEW

2.1 AMF SYSTEM

The Airborne Measurement Facility System Concept, shown in Figure 1, illustrates the acquisition of 1030 or 1090 MHz Secondary Surveillance Radar (SSR) and TCAS data along with other data for ground-based analysis. The AMF system design includes receivers, pulse and reply detection processors, auxillary data acquisiton elements and data recording facility as shown in Figure 2.

Pulse data received on the three antenna systems are fed into the AMF Receiver Processor (AMFRP): two omnidirectional blade antennas and a four-monopole angle of arrival antenna. The two blade antennas, located on the top and bottom of the aircraft, are used by the AMFRP amplitude receiver inputs. Similarly, the angle of arrival antenna, located on top of the aircraft, is used by the angle of arrival receiver input. The Receiver Processor contains two log-video amplitude receivers and one angle of arrival receiver. The video output signals from these receivers are sampled and digitized by analog-to-digital converters and stored in a buffer memory. The sampling, buffer storage, and control signals are generated in the processor. The Receiver Processor transmits the buffer memory data to the Aircraft State Unit upon command. The Aircraft State Unit (ASU) performs data multiplexing as required to allow the insertion of information such as the time of day and number of data words processed each second (see Appendix A for additional details). The ASU feeds the continuous data stream to the AMF Recording Rack (see Section 3). Primary power for the Receiver Processor and the ASU is distributed via the Power Distribution Box. (For more details, see Reference [1].)

The AMF consists of four primary units, which are the Receiver Processor, the Aircraft State Unit, the Power Distribution Box, and the AMF Recording Rack. Like the original AMF, the upgraded system is small enough for installation in an aircraft or a ground vehicle. The AMF is illustrated in Figure 3, excluding the Recording Rack, which is described in Section 3.

During a flight session, the AMF will detect, process, and transfer Mode S, ATCRBS, or TCAS surveillance data at 2 Mbits/sec to the recording system. These surveillance data are beacon radar pulses sampled by A/D converters in the AMF Receiver Processor. The AMF operates in either of two operating modes. In the first mode, referred to as Pulse Mode, each pulse is detected and sampled on one of the ATC frequency bands (i.e., 1030 MHz or 1090 MHz). The second mode, referred to as Mode S and operating only on the transponder downlink frequency (1090 MHz), detects the Mode S preamble and interprets the subsequent pulse position modulated 56-bit message.

The AMF, altimeter, GPS receiver, and Mode S transponder transfer data to the recording system for storage onto 8-mm tape cartridges. The AMF, depending on its operational mode and frequency, collects data transmitted by the Air Traffic Control Radar Beacon System (ATCRBS) or Mode S Secondary Surveillance Radar, TCAS units, and Mode S transponders. The altimeter determines the host aircraft's altitude. The GPS receiver provides the host aircraft's location. The Mode S transponder transfers received TCAS broadcast transmissions to the recording system. It is dedicated to the AMF recording system, independent of the ship's transponder, and is inhibited from transmitting any surveillance replies.

Once system initialization is complete, the operator can monitor the system by observing the laptop's real-time display. The monitoring display windows are interactive and the user controls the volume of information being displayed. Simultaneously, any number of real-time display functions may be run. Further information on monitoring and quick-look functions are described in Section 5. After completing the flight test, the operator performs system shutdown and removes the data cartridge from the 8-mm tape drive. Upon arrival at the laboratory, data can be retrieved in a matter of minutes using a computer compatible with the airborne recording system. Additional details for using and maintaining the AMF can be found in the AMF User's Manual [2].

2.2 DATA ANALYSIS

Detailed data analysis is performed on collected measurements using non-real-time software. Typically, the data are read and organized so that each recorded pulse can be examined. Depending on what type of output is desired, a large number of algorithms can be used to analyze these pulses. An example of the type of studies that may be performed on collected data is illustrated in Figure 4. All SSR and environment characterization, GPS, altitude, and transponder analysis functions listed in the Data Analysis Overview diagram (Figure 4) are available. The recording system data format has been updated to include all these functions.

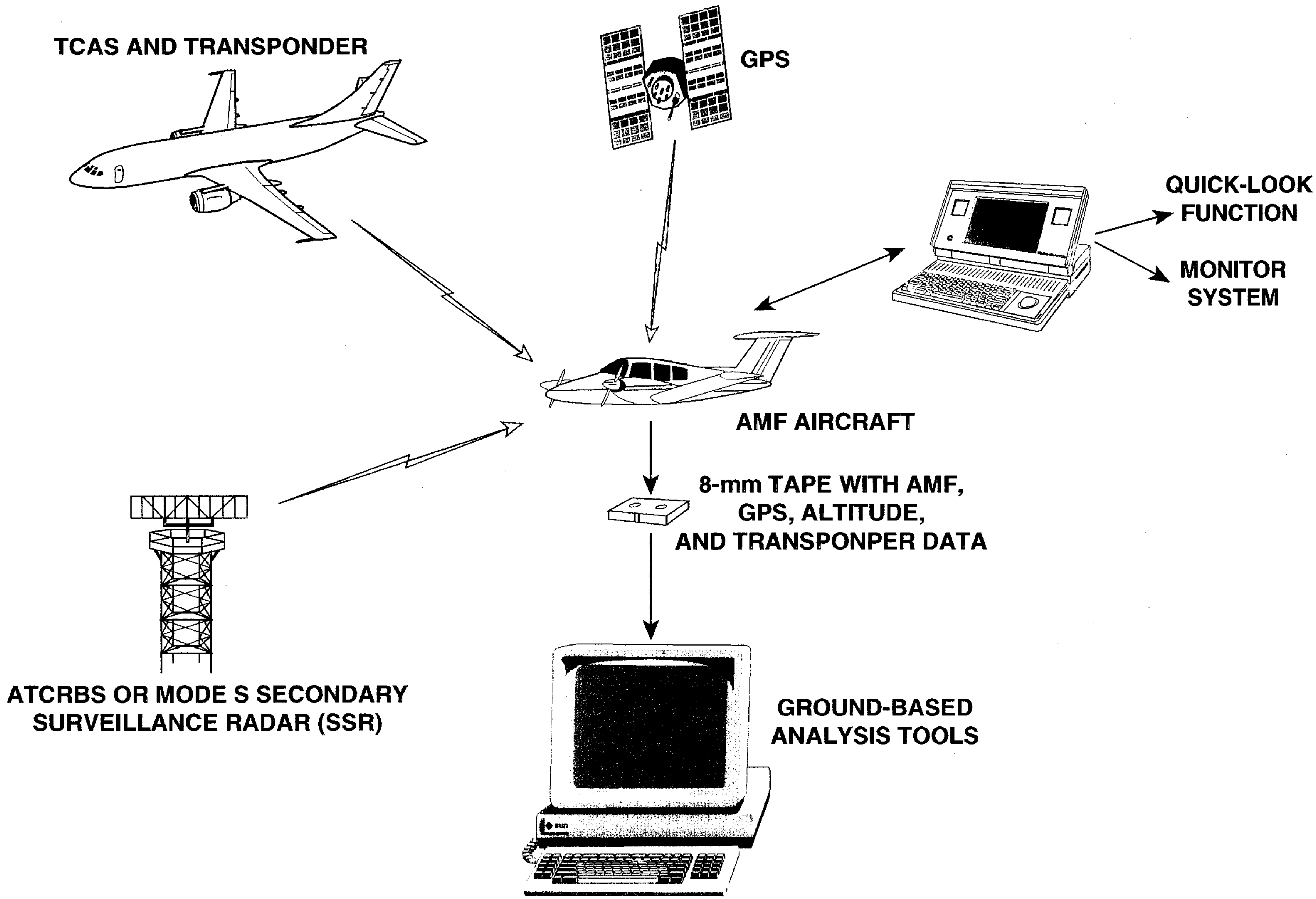

Figure 1. AMF System Concept.

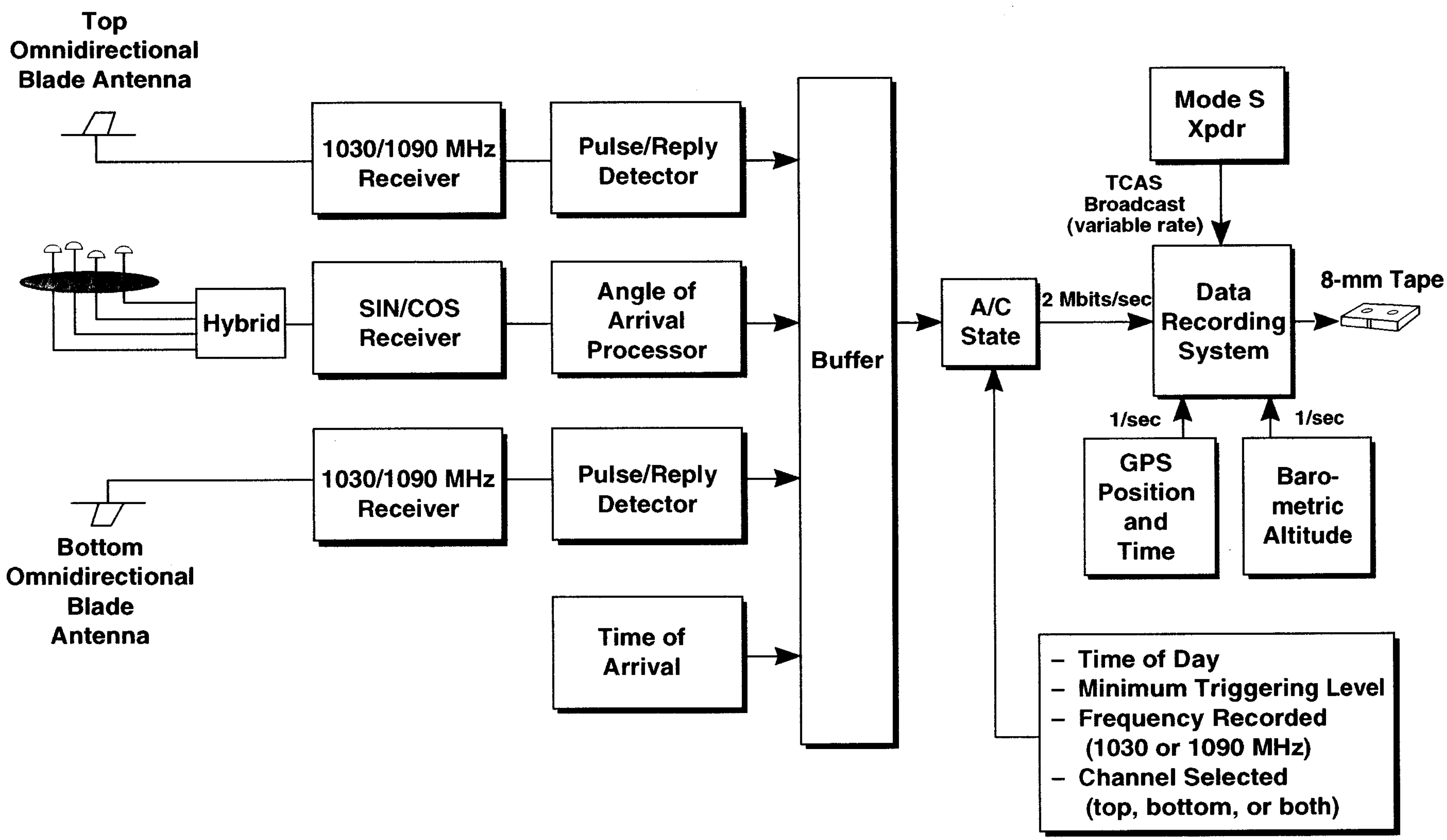

Figure 2. AMF System Architecture.

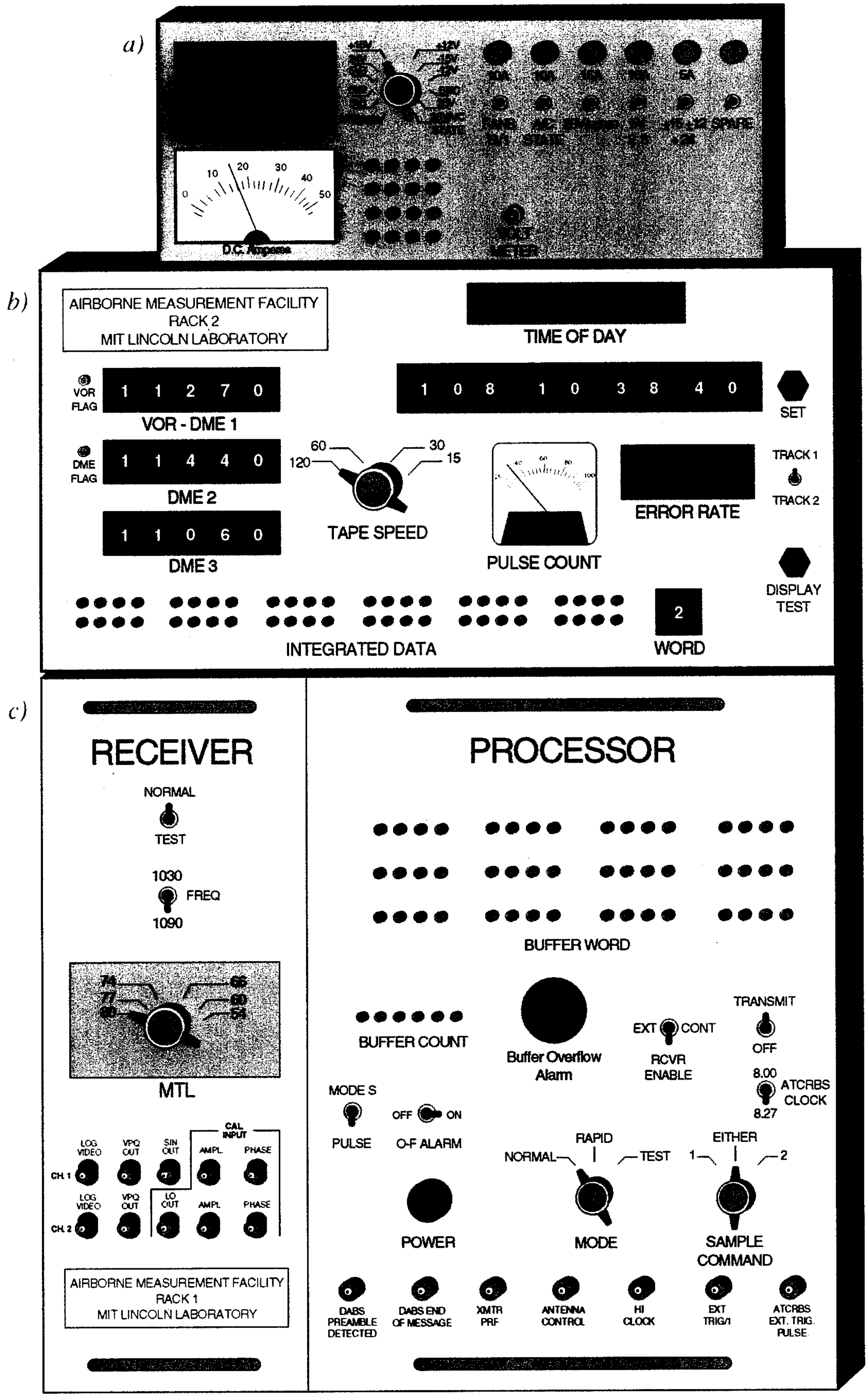

Figure 3. AMF consisting of a) Power Distribution Box, b) Aircraft State Unit, and c) Receiver Processor.

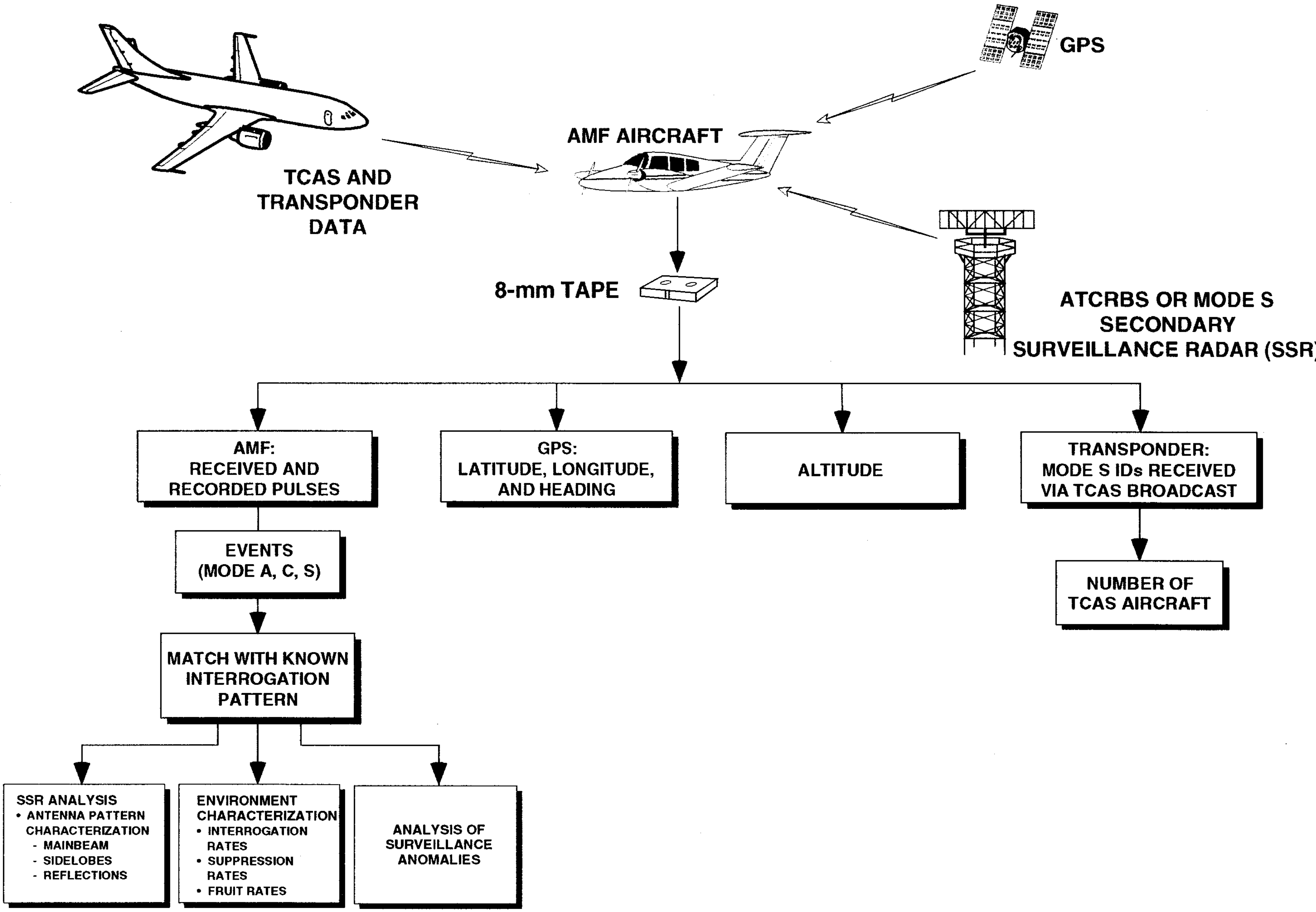

Figure 4. AMF Data Analysis Overview.

3. AMF RECORDING SYSTEM DESIGN

The AMF Recording System is a self-contained recording rack that carries all data acquisition system equipment and data sources other than the AMF Receiver Processor. The AMF recording rack (shown in Figure 5) contains: a VME-based high-speed data acquisition system, a Sun laptop computer [3], an altitude encoder [4], a GPS receiver [5], a Mode S transponder [6], and a moving map display [7, 8]. All power outlets, antenna connections, and equipment circuit breakers are centralized at the back of the unit as illustrated in Figure 6.

A conventional VMEbus architecture is used to store data on an 8-mm data cartridge tape [9]. All I/O devices (data sources, laptop computer, and tape drive) are connected to the VME-based system via the custom built I/O transition box. This box contains I/O boards that interface to the data processing boards located within the avionics chassis.

Communication between the SUN laptop computer and the VME system is by an Ethernet Link. This allows the user to transfer commands and receive real-time data during data collection. Simultaneously, a direct connection between the laptop computer and the recorder I/O transition box allows the system to tap into the VME computer boards and monitor all recording activities.

Although it is not a critical part of the recording process, a moving-map display was added to the recording rack. GPS position and aircraft gyro heading information of the aircraft are provided to the display during an AMF recording session. For additional details, see Reference [8].

3.1 THE VME-BASED COMPUTER SYSTEM

The AMF Recording System is composed of four VME boards: a record processor, an auxiliary processor, an AMF interface, and a Mode S transponder interface board. The record processor and auxiliary boards are identical Motorola MVME-167 single board computers. The AMF interface board is a BSI 4411 Decommutator processor board developed by Berg Systems Inc., and the Mode S transponder interface board is a VMIC VMIVME-6005 Communications Controller board. Refer to Figure 7 for an illustration of the computer system design. All four VME-based boards reside in the rack's avionics chassis and communicate over the VME bus. The following paragraphs offer additional details about each board's hardware features.

3.1.1 Record and Auxiliary Processing Boards

The record and auxiliary MVME167 processing boards are based on the MC68040 microprocessor. The MVME167 board's main features include: 4 Mb of DRAM, 8 Kb of static RAM, time of day clock, Ethernet transceiver interface, four serial ports, A32/D32 VMEbus master/slave interface, 128Kb of static RAM, and VMEbus system controller. The I/O on the MVME167 is connected to a special VMEbus connector, also known as a P2 transition board. The MVME167 is connected through the P2 transition board to the MVME712M transition board. The MVME712M transition board, housed in the I/O transition box, provides configuration headers and industry standard connectors for the I/O devices. See References [10, 11, and 12] for additional details.

The Record Processor is responsible for the primary system functions. It receives, processes and records the AMF data and auxiliary data blocks onto an 8-mm tape cartridge. It interprets all operator commands received from the SUN lap-top computer, and it maintains and writes directory information onto the 8-mm tape cartridge. When playing back recorded data, a library of routines that employs the directory information is used to search the tape to a desired location (i.e., either by the start of a recording session or by a specific time-of-day). This capability is ideal for locating a desired record in a long recording session.

The Auxiliary Processor, the second Motorola CPU board, is responsible for receiving, processing and forwarding data from the GPS unit, altimeter, and Mode S transponder to the record processor. This board also transmits real-time data back to the SUN laptop. For this job, commands to display real-time data are issued via the SUN laptop to the record processor. The record processor interprets and forwards the commands to the auxiliary processor, which in turn transfers the specified data to the SUN laptop (for more details, refer to Section 5.2).

3.1.2 AMF Interface Board

The BSI 4411 Decommutator processor board was specially modified for MIT Lincoln Laboratory by Berg Systems Inc., and functions as the input interface to the AMF. The 4411 is configured by means of a parameter file. During the initialization phase, this file is read by the record processor, interpreted, and its commands are sent over the VMEbus to configure the 4411 and prepare it for operation. Functionally, the 4411 double-buffers data in memory and sends an interrupt to the record processor when one memory bank becomes full. While the record processor is reading the data from memory, the 4411 continues buffering data in its other memory bank. This buffering and interrupt scheme continues throughout the recording session. For additional details, see Reference [13].

3.1.3 Transponder Communications Board

The VMIC VMIVME-6005 Communications Controller board functions as the interface between the Mode S transponder and the auxiliary processor CPU board. To communicate with the transponder, the VMIC board transmits messages via the ARINC429 data bus. Every time a message is transmitted an interrupt is issued to signify that the message has been completely written. In a similar manner, when a TCAS broadcast is received by the Mode S transponder and routed to the VMIC board, an interrupt is issued to notify the auxiliary processor that a message has been received and requires processing. Software to interface with the transponder is quite extensive; the auxiliary board performs both the initialization and software control for the VMIC-6005 Communication Controller. Refer to Reference [14] for additional board documentation.

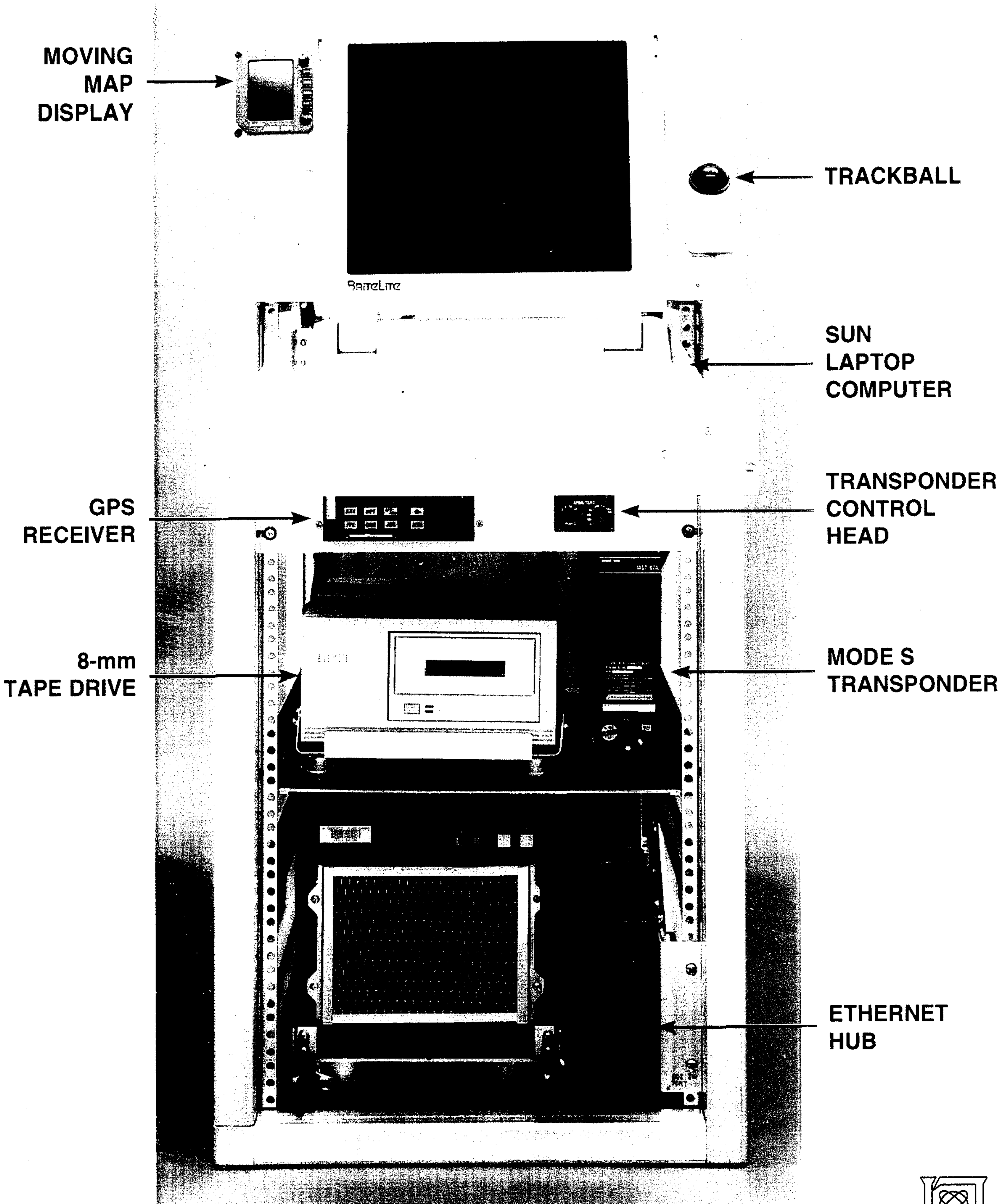

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Figure 5. The AMF Recording Rack, front view.

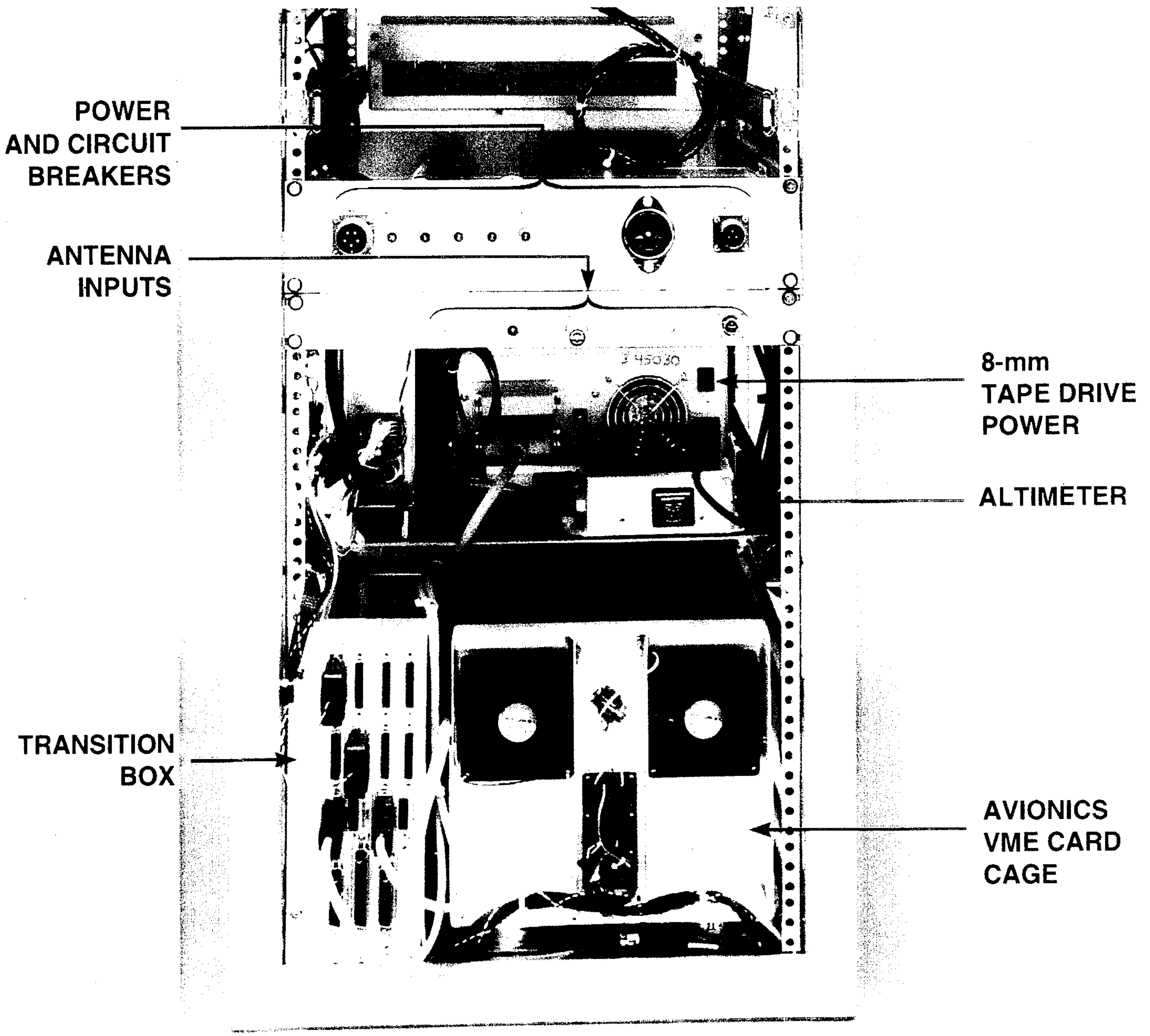

Figure 6. The AMF Recording Rack, rear view.

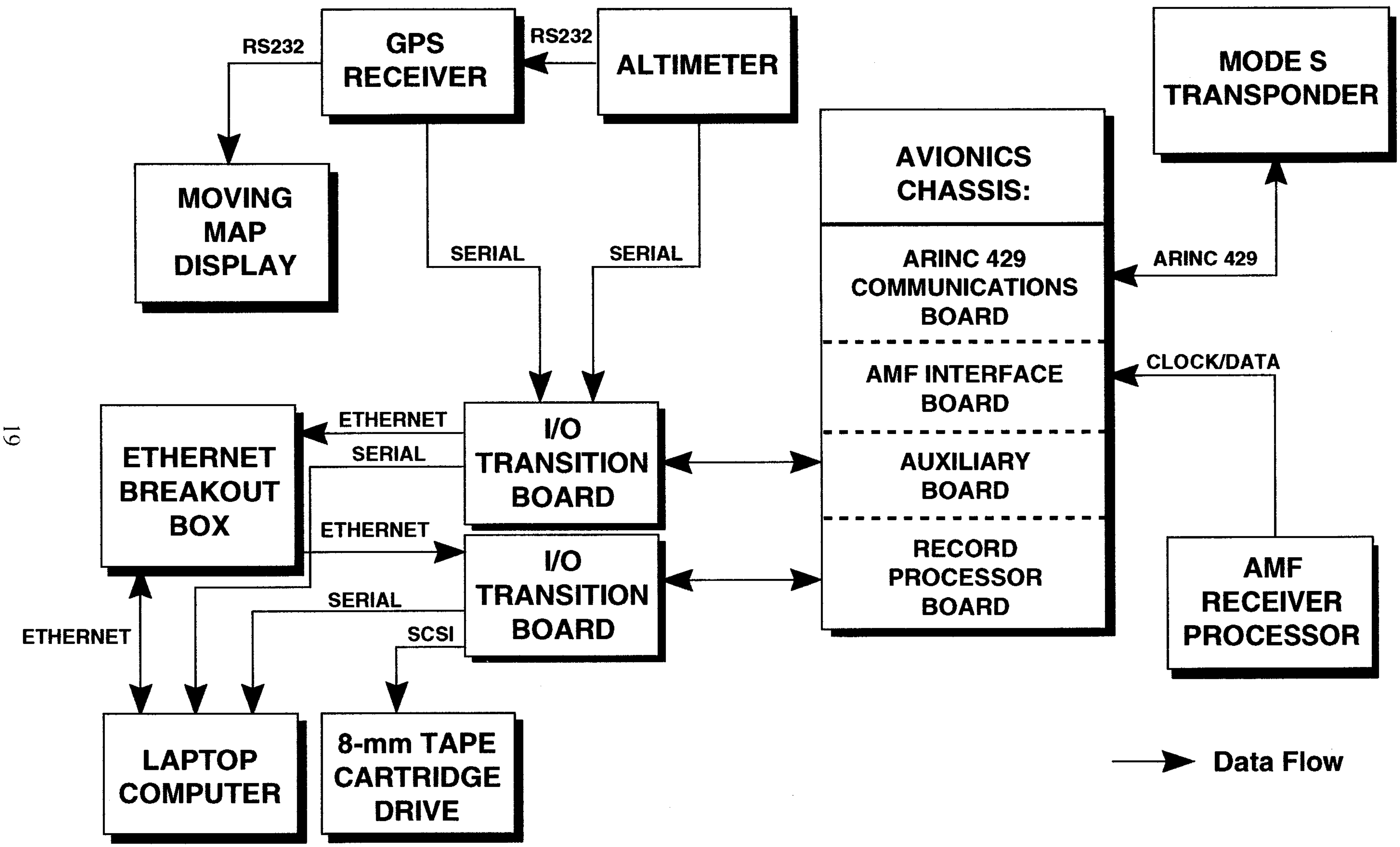

Figure 7. AMF System Design.

3.1.4 Test Simulator Board

Although not a part of the recording system, a BSI 4416 Simulator board is used for system testing. It is not a permanent resident in the chassis; instead it is inserted and used in the avionics chassis as needed. By connecting the BSI-4416 Simulator Board to the BSI-4411 AMF interface board, the operator can test the recording system by configuring the 4416 to output simulated AMF data. The 4416 is configured much like the 4411. During the initialization phase, a file is read by the record processor, interpreted, and its commands are sent over the VMEbus to configure the 4416 and prepare it for operation. For additional details please refer to Reference [15].

3.2 THE REAL-TIME SOFTWARE

At the heart of the software is the VxWorks operating system contained in the Motorola CPU boards. This operating system provides the building blocks for running applications in a real-time multi-tasking environment. VxWorks includes a fast and flexible run-time system and a UNIX cross-development package [16, 17].

Since software development for VxWorks requires a UNIX host development system, our network of existing Sun Workstations was used for this purpose. Application modules in C are compiled with the UNIX C compiler. These application modules do not need to be linked with the VxWorks system libraries or even with each other. Instead, VxWorks is capable of loading the UNIX-generated object modules directly, using the symbol table contained in all UNIX-generated object modules, to dynamically resolve external symbol references.

This multitasking environment allows real-time applications to be constructed as a set of independent tasks, each with its own thread of execution and set of system resources. The intertask communication facilities allow these tasks to synchronize and communicate in order to coordinate their activity. The VxWorks multitasking kernel uses interrupt-driven, priority-based task scheduling. It features fast context switch times and low interrupt latency. Thus, any C subroutine may be spawned as a separate task, with its own context and stack.

3.3 SOFTWARE MAINTENANCE AND INSTALLATION

The Sun laptop is a SPARC-based machine running version 4.1.3 of SunOS. Maintenance of the AMF recording system software is performed by the system administrator, who routinely makes software backups. Several copies of the latest software version were made to ensure that the software can always be recovered. In addition, all software modifications are recorded in a written log.

Installation of the AMF Recording System software is performed each time the avionics chassis is reset. Upon reset, a script file, which resides on the SUN lap-top computer, issues commands to perform the down-loading of both the application software and the VxWorks image into the MVME-167 single board computer's ROM. Once the software is down-loaded, initialization is performed via the SUN lap-top which establishes communication channels to the computer boards.

Inter-processor communication is done by Ethernet-based sockets. Sockets are a UNIX-compatible mechanism for exchanging byte streams between tasks. Data transfer via sockets is the method used by the SUN lap-top computer to receive status/monitoring information from the record and auxiliary processors, as well as real-time data from the auxiliary processor. Sockets are also used by the tools on the Sun laptop to transfer commands and data among themselves. Refer to Appendix B for a complete description of the real-time software tasks.

4. THE GRAPHICAL USER INTERFACE

The enhanced AMF Recording System provides a Graphical User Interface (GUI) to allow the user to control and monitor the entire recording system. This provides in flight monitoring of system performance and data reliability, and allows the user to perform advanced real-time analysis on incoming data. A library of Xview-based GUI tools, which run in the OpenWindows environment on the laptop computer, comprises the following 3 GUIs:

- amfcontrol - operator interface to the recording system.
- amfdatagrabber - operator interface for real-time data analysis functions.
- amftapeplayer - operator interface for tape playback functions.

The user controls data acquisition by means of the laptop computer, through which commands are issued to the AMF Recording System over the Ethernet link. The Ethernet link is also used to transmit data back to the laptop computer during data collection for real-time data analysis. Figure 8 shows the SUN lap-top screen with the control tool and status windows present. Additional details regarding these tools is provided in the following paragraphs.

4.1 THE CONTROL TOOL

The control tool (amfcontrol) as shown in Figure 9 is interactive. This menu driven display offers a simple method for initiating and terminating data recording throughout each recording session. Pertinent information as specified by the user is automatically stored in data header and summary files on the 8-mm cartridge tapes. Additionally, the operator may input status messages into the data stream at any time. The header and summary blocks do not affect the recorded data, and only serve as additional information sources during analysis. For a full description of operating procedures see the "AMF User's Manual" [2].

4.2 REAL-TIME DATA ANALYSIS TOOL

Real-time data analysis is extremely valuable. For example, a researcher may be interested in comparing squitters received by the AMF Receiver Processor to tail numbers of aircraft actually observed during data acquisition. These real-time results may determine whether adjustments need to be made on subsequent data gathering missions.

Real-time data analysis and display are controlled by means of the laptop computer via the amfdatagrabber tool (see Figure 10). Commands to obtain data are issued to the recording system over the Ethernet link. The Ethernet is also the pathway used to pass real-time data back to the laptop, where it is piped into local analysis functions, also known as Quick-Look Functions.

The Quick-Look real-time software was developed with expansion in mind, i.e., researchers can add analysis functions to the system when needed. Currently, the following functions are available:

- data_parse — general purpose analysis function.
- disSquitter — displays the Mode S squitters (IDs) received by the AMFRP.

- disAll — displays the channel 1 and channel 2 pulse amplitudes, and the angle of arrival received by the AMFRP.
- disRate — displays the rate per second of received pulses on channels 1 and 2.

See the AMF User's Manual [2] for a full description of operating procedures.

4.3 MONITORING

Continually monitoring incoming information assures the researcher of proper system operation. Because the system was designed with flexibility in mind, additional monitoring information may be added or removed by software modifications. As shown in Figure 8, there are four windows on the laptop screen that are used to monitor the system. The **proc1_stat** window receives status messages from the record processor VME board via the Ethernet link, which may be checked to determine the recording status. The window partially obscured by **proc1_stat** is called **amf-vme1** (connected to the console port) and offers more detailed output concerning system operation. The two remaining monitor windows, **proc2_stat** and **amf-vme2,** provide the equivalent functionality for the auxiliary processor.

Each time a particular data type is recorded, whether it be AMF, GPS, altimeter, or transponder, the number of bytes that it contains will be displayed in the **amf-vme1** window. All data type records are of fixed-length, with the exception of the AMF data record which varies depending on the surveillance environment. Because the display windows are interactive, the volume of monitoring information may be adjusted at any time during data collection.

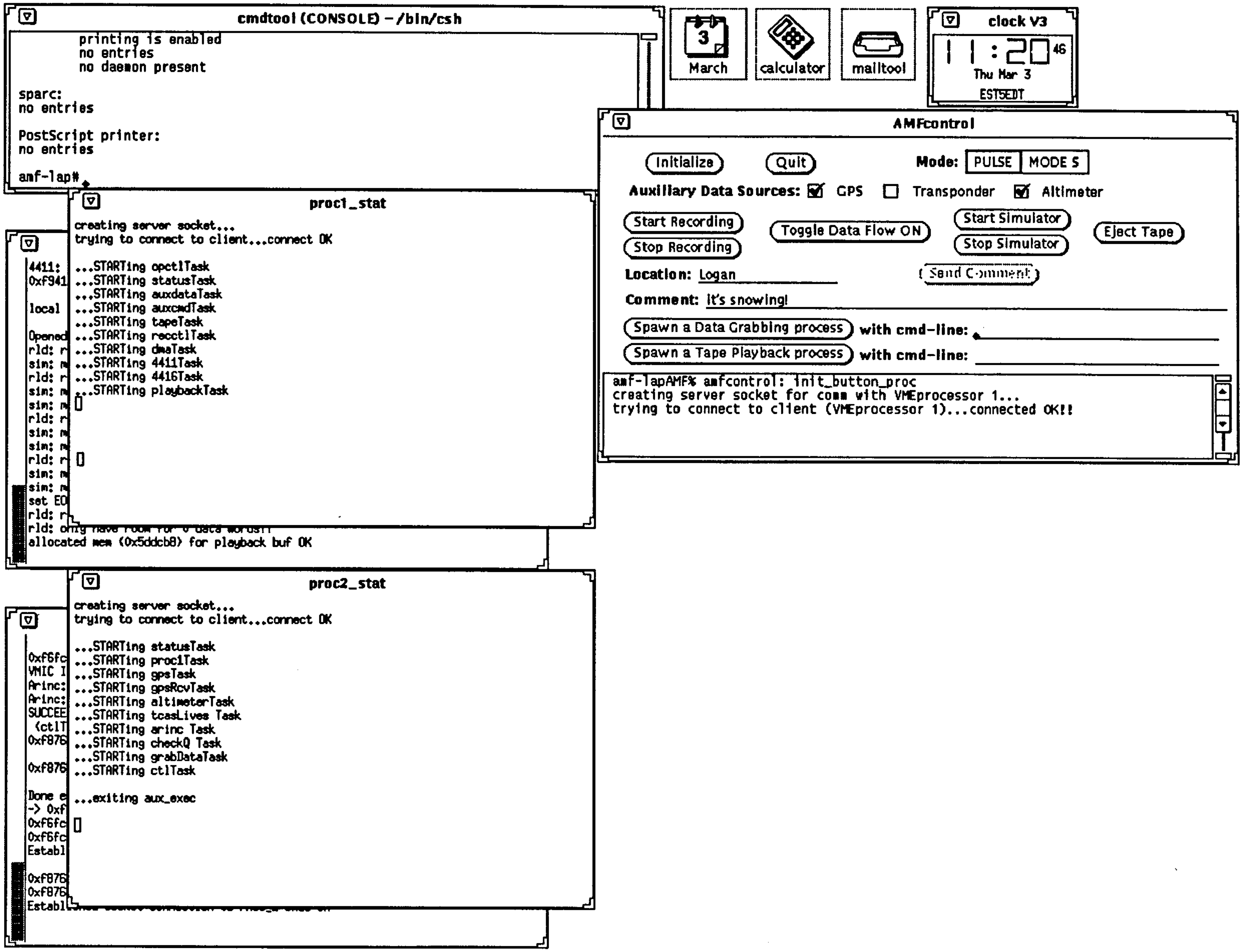

Figure 8. Graphical User Interface (GUI) After Initialization.

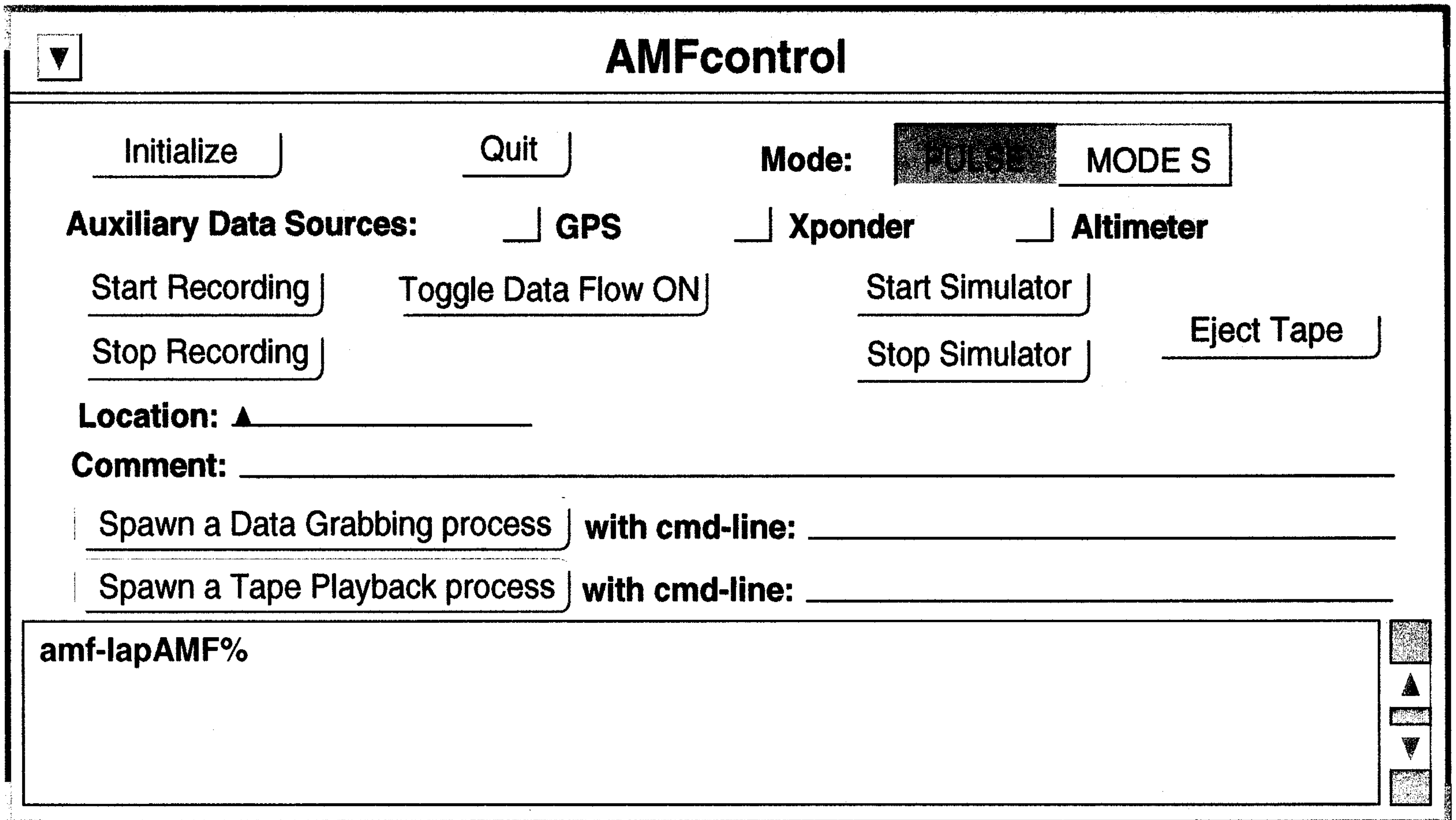

Figure 9. The GUI Control Tool.

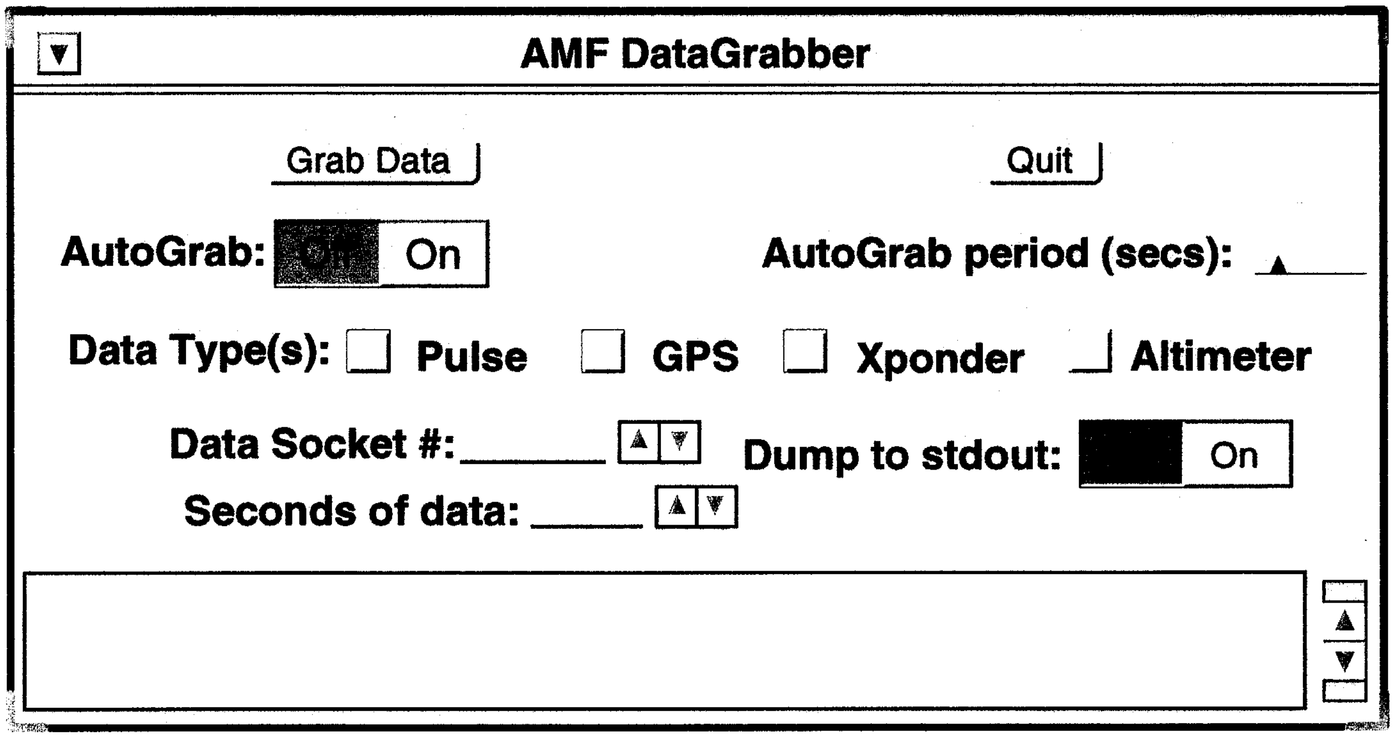

Figure 10. The Real-Time Data Analysis Tool.

4.4 THE TAPE PLAYBACK TOOL

Recording sessions can be easily initiated and stopped any number of times during data collection, so there may be a multiple number of sessions on any one tape. Once a recording session has been completed, the user can play back the recorded data using a SUN workstation tool labeled **amftapeplayer** as illustrated in Figure 11.

The AMF Recording System can be operated up to 5 hours and 53 minutes continuously at the peak data rate, representing 42.4 Gbits of data. To handle this much data, the researcher can use a table of contents, also referred to as a directory, which is created for each session and written to tape immediately after the data session ends. When playing back the recorded data, a library of routines that employs the directory information is used to search the tape to a desired location (i.e., either by the start of a recording session or by a specific time-of-day). This capability is ideal for finding a particular event in a long recording session. Depending on which mode is chosen by the operator, the directory files are searched sequentially until the session number or the desired time-of-day is located. The tape is then positioned at the correct record within that recording session and the playback commences. Commands are issued to the system over an Ethernet link to read from the 8-mm tape drive. The data is passed back again by Ethernet where it can be stored to a file or passed to an analysis function. Refer to the AMF User's Manual [2] for a full description of operating procedures.

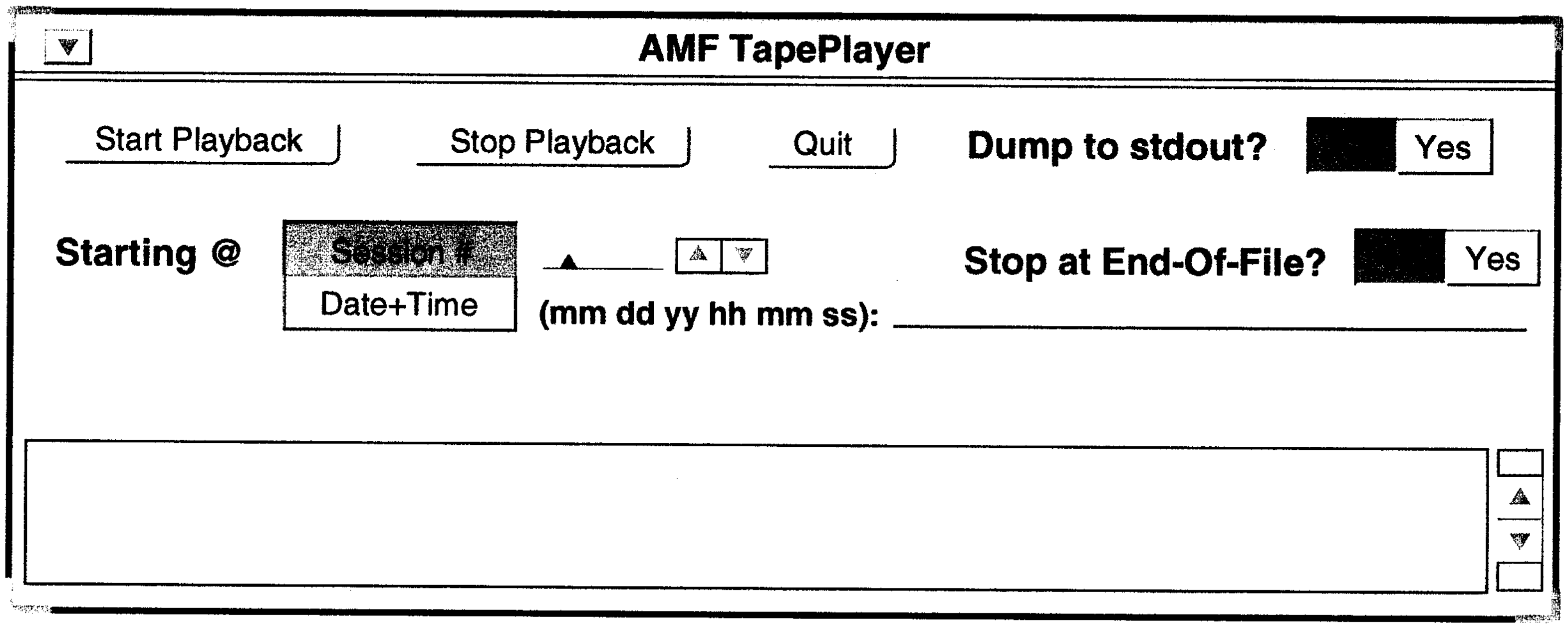

Figure 11. The Tape PlayBack Tool.

5. DATA FORMAT

The data stream contains integrated data blocks from all available data sources as illustrated in Figure 12. Data are passed to the recording media in 240 Kbyte blocks to ensure a recording rate margin over the maximum 256 Kbyte/sec throughput rate. Pertinent information about the recording configuration is automatically written to the beginning and end of the tape, labeled as the session header and session summary. This information does not affect the recorded data, and only serves as a helpful tool during analysis.

Following the initial session header blocks is a continuous stream of data blocks, referred to as "records," corresponding to each of the data sources (AMF, GPS, altimeter, or transponder). Although each has a unique data format, they all share similar record header blocks to help interpret recorded data. Record header information consists of a data type record, block length, sequence number, and time stamp. All data types, with the exception of transponder data and operator comment records, are received and recorded once per second. Transponder data only reflects TCAS broadcasts, and so its rate depends on the number of TCAS aircraft in the surrounding vicinity. Operator comments are passed to the system via the GUI, as described in Section 4. This record type allows the operator to include any chosen message into the data stream at any given time. If a data source is not available, no corresponding data blocks for that source will be found. A general description of the recording system's data types is described in Appendix A.

Recording sessions can be easily initiated and stopped any number of times during data collection, so there may be a multiple number of sessions on any one tape. Each recording session is followed by its own directory file, which offers a method for efficient data retrieval by searching the tape for a specific session or time of day.

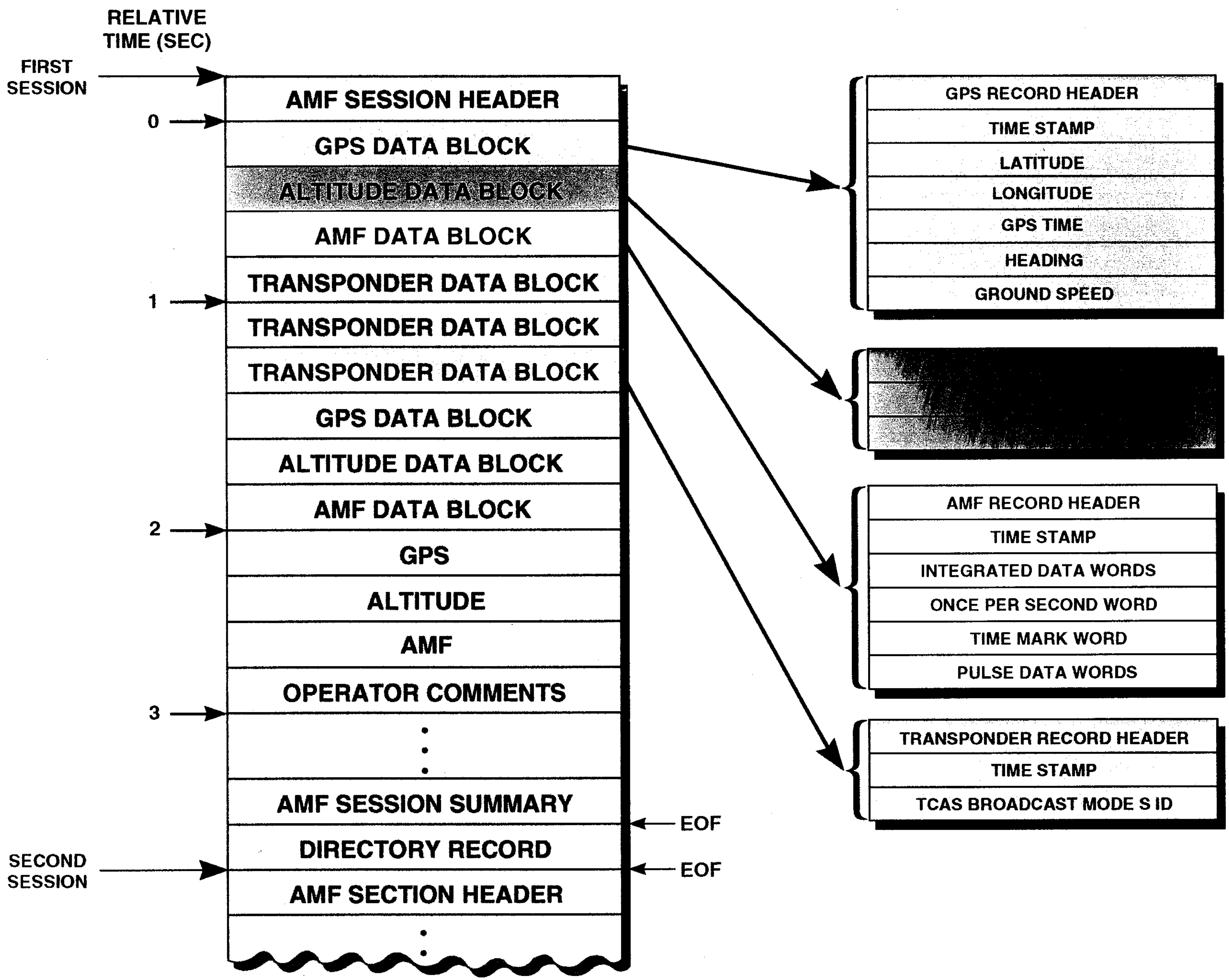

Figure 12. AMF Data Format.

6. SUMMARY

The Air Traffic Surveillance Group has completed development of a high speed VME-based recording system enhancement for the AMF (Airborne Measurement Facility). The AMF is a data collection system which provides a means of gathering and recording secondary surveillance (beacon) radar data.

The upgraded AMF Recording System provides an increased recording capacity and is easy to use and maintain. Continuous recordings for up to 5 hours at the peak data rate can be made, representing 5.3 Gbytes of data. A real-time display was added to the system, allowing a researcher to obtain situational awareness during a data collection. The original AMF was limited to recording surveillance data only, whereas the upgraded AMF now allows the user to include data recording from other sources such as a Mode S transponder, a GPS receiver, and an encoding altimeter. In addition, plans are underway to enable simultaneous 1030 and 1090 MHz measurements, acquisition of long Mode S replies, a larger pulse data buffer, and other enhancements to reduce weight, ease operation and eliminate reliance on difficult to obtain parts.

The enhanced system is portable, which allows operation of this measurement and recording tool while located in aircraft and ground vehicles. Two portable racks were constructed to contain all data acquisition equipment and data sources, and the AMF Receiver Processor, Aircraft State Unit, and Power Distribution Box.

Today, AMF measurements are being used to support the GPS-Squitter, Mode S, and TCAS programs. The AMF continues to be a unique data collection tool for current and future generations of researchers and analysts.

APPENDIX A. THE RECORDING SYSTEM'S DATA FIELDS

A general description of the data types is provided below. The AMF Recording System accepts AMF, GPS, altitude, and transponder data. Each type has a unique data format; however, they all share similar header blocks to help interpret recorded data. Header block information consists of a data type record, block length, sequence number, and time stamp.

A.1 SYSTEM TIME

Precise time resolution is critical to the successful operation of the AMF system. To achieve this, the AMF time-stamps each pulse upon its receipt. The timing mechanism consists of two unique clocks: time-of-day (TOD), and time-of-arrival (TOA). The AMFTOD clock provides the hour, minute, and second based on the initial information entered by the user on the front panel of the AMF Aircraft State Unit.

Each second's worth of data, referred to as a "record," will contain many pulse words. Thus, the AMF is able to (a) assign a specific TOA to each individual pulse data word in the AMF Receiver Processor (AMFRP), while simultaneously (b) time stamping each record with the appropriate system AMF Aircraft State Unit TOD. Once a record is transferred to the Recording System, it is automatically time stamped with the appropriate system TOD regardless of whether the record source be AMF, GPS, altimeter or transponder. The Recording System TOD uses GPS time; if GPS time is not available, reference is made to the laptop computer's internal clock. The AMF Aircraft State Unit TOD and the Recording System TOD are two distinct clocks. By resetting the AMF Aircraft State Unit TOD at the outset of operation, the user ensures that the AMF Aircraft State Unit time is identical to the Recording System TOD at the beginning of each record. No action is taken by the system if the AMF Aircraft State Unit TOD clock is not reset. In fact, if the Aircraft State Unit TOD is not current, the Recording System TOD is used during data analysis. In contrast, the AMF Receiver Processor TOA clock does not rely on any user input and is always generated by the AMFRP.

A.2 AMF DATA

Surveillance data, received on either the 1030 or 1090 MHz frequency bands, consist of received beacon radar pulses which are sampled and digitized by analog-to-digital converters and then stored in the AMF's buffered memory. In the nomenclature used in the original AMF, detected pulses create "pulse data words" in the AMF's buffered memory. As an artifact of the earlier analog data recorder, when there are no pulses to be recorded, "filler words" are generated so that at all times a constant 2 Mbit/sec data stream is transmitted to the recording system. All filler words are automatically removed by the VME-based recording system. The AMF can be operated in either of 2 modes:

- Pulse Mode (available for both 1030 and 1090 MHz frequencies), which detects and samples each pulse upon receipt. This mode is very useful for doing antenna pattern characterization (e.g., mainbeam, sidelobes, and reflections) or environment characterization (e.g., interrogation rates, suppression rates, and fruit rates). Pulse Mode was referred to by the AMF original designers as the Air Traffic Control Beacon System (ATCRBS) Mode on the AMFRP.

- Mode S (available only for 1090 MHz frequency), which detects the Mode S preamble and interprets the following pulse position modulated 56-bit message. This mode is used for displaying real-time squitters, as much of the data processing (i.e., interpretation of 56-bit message) is accomplished before it is transferred to the recording system. Currently, the AMF detects 112-bit Mode S replies, but only interprets and records the first 56 bits of the message. Future AMF enhancements will include the capability to record long Mode S replies (112 bits).

In Pulse Mode, the data format for the uplink (1030) and downlink (1090) is similar. The primary difference being in the use of an 8 MHz time-of-arrival clock for uplink measurements and an 8.27 MHz clock for downlink measurements. The downlink clock frequency accommodates an integer (12) sampling of the 1.45 μsec spacing of reply pulses. The TOA clock operating frequency is determined automatically by the system at the time that the user selects the mode of operation.

As described in Section 2, data come from 3 antenna systems. The two omnidirectional blade antennas, each located on the top and bottom of the aircraft, are used by the AMFRP amplitude receiver inputs. The four-monopole angle antenna, located on top of the aircraft, is used by the angle receiver input. Upon detection of a received pulse (or if Mode S, the preamble), the processor collects amplitude and angle samples, and generates a pulse data word containing the TOA, two amplitude samples, one pulse width count, and an angle of arrival sample [1]. If operating in Mode S, four additional pulse data words are recorded that contain the 56-bit Mode S reply.

The AMF produces a 2 Mbit/sec serial bit stream that is composed of 64-bit words, each consisting of a 48-bit data word and a 16-bit checksum. The original AMF used the checksum in two different ways. While recording, the data on the instrumentation tape was simultaneously read back and fed to the Aircraft State Unit where the cyclic code was checked to detect errors that may have occurred as a result of tape discontinuities. The number of errors was displayed on the AMF Aircraft State Unit. During ground playback, data words containing detected errors were discarded.

Currently, the AMF Recording System provides the ability to monitor the entire Recording System (see Section 4). Each time a particular data type is recorded, the number of bytes that it contains will be displayed in the GUI. Additionally, the data being recorded may be validated using real-time analysis software. Tape playback software is used to check each record for its appropriate length and sequence number; if an error is found, the record is discarded. While recording, the 8-mm tape drive cannot be read back, and therefore the checksum provides no functionality during data collection. However, future enhancements could engage the checksum to detect and discard faulty data words during tape playback.

Six different 64-bit word types are generated to define the surveillance measurements, time and AMF settings. They include: Sync Words, Pulse Data Words, Integrated Data Words, Time Mark Words, Once-per-Second Words and External Trigger Words. Sections A.2.1 through A.2.6 that follow provide additional details regarding these words.

A.2.1 Sync Words

The sync code is a 64-bit code which is inserted into the data stream once each second. The Sync Code is used by the recording system to detect the start of a one second AMF data block.

A.2.2 Pulse Data Words

Upon detection of a received pulse, the processor generates a pulse data word containing the time-of-arrival, an angle of arrival sample, two amplitude samples and one pulse width count. The two amplitude samples correspond to the signals received on the omnidirectional blade antennas mounted on the top and bottom of the aircraft. The storage of pulse data words is always initiated by the arrival or continued presence of a pulse in one of the amplitude channels during the time the processor is enabled. The first pulse to arrive on a selected channel will initiate an amplitude and a width sample, and the formation and storage of a pulse data word. Whenever a sample is taken, both amplitude channels and angle of arrival channel are sampled regardless of whether or not a signal is present above the minimum threshold level (MTL). The AMF's pulse standard-width interval is one clock period (1/8 MHz = .125 µsec) for the 1030 MHz frequency band and one clock period (1.45/12 MHz ≈ 0.12 µsec) for the 1090 MHz frequency band.

A.2.3 Time Mark Words

A time mark word is generated each time the least significant 16 bits of the TOA clock overflow. The time mark word and the TOA (contained in the pulse data word) provide the resolution required for subsequent data analysis. Each second, there are 123 time mark words when using the 8 MHz TOA clock ($\frac{1}{2^{16}}$ counts x 8M); whereas, there are 126 time mark words when using the 8.27 MHz clock. See Figure A-3b.

A.2.4 Once-Per-Second Words

A once-per-second word is generated each second and contains both the time mark word and the pulse data word time corresponding to the time at which the AMF Aircraft State Unit TOD clock turns over. See Figure A-3b. This allows one to relate TOA with TOD.

A.2.5 Integrated Data Words

Four integrated data words are generated every second. They contain: the time-of-day clock, the number of pulses processed each second, the minimum threshold level (MTL) at which data are being recorded, and the mode of operation (1030 vs. 1090). The number of pulses contained in this data word is redundant, as the data acquisition system also writes the number of bytes contained in each block in the block header. In the original AMF design, the integrated data words contained aircraft state and position information. This capability has been replaced by the enhanced AMF system using GPS data.

A.2.6 External Trigger Words

Whenever an external trigger is fed to the unit, it causes the processor to store a word referred to as the External Trigger word, which contains the count of the complete 32-bit time-of-arrival clock at the time the trigger occurred. In addition, a bit is set in the first data word following the trigger to identify it as such. This allows a rapid determination in playback processing of the time elapsed from the trigger to the first received pulse.

Figures A-3a-f contain detailed descriptions of the AMF data fields.

A.3 AUXILIARY DATA

The data fields corresponding to the altimeter, GPS, and transponder data sources are shown below in Table A-1.

Table A-1. Auxiliary Data Types

Data Source	Associated Fields
GPS	GPS time latitude longitude heading magnetic heading ground speed altitude mode number of satellites being tracked
Altimeter	host aircraft's pressure altitude
Transponder	nearby TCAS broadcast messages that include the Mode S address of the transmitting aircraft

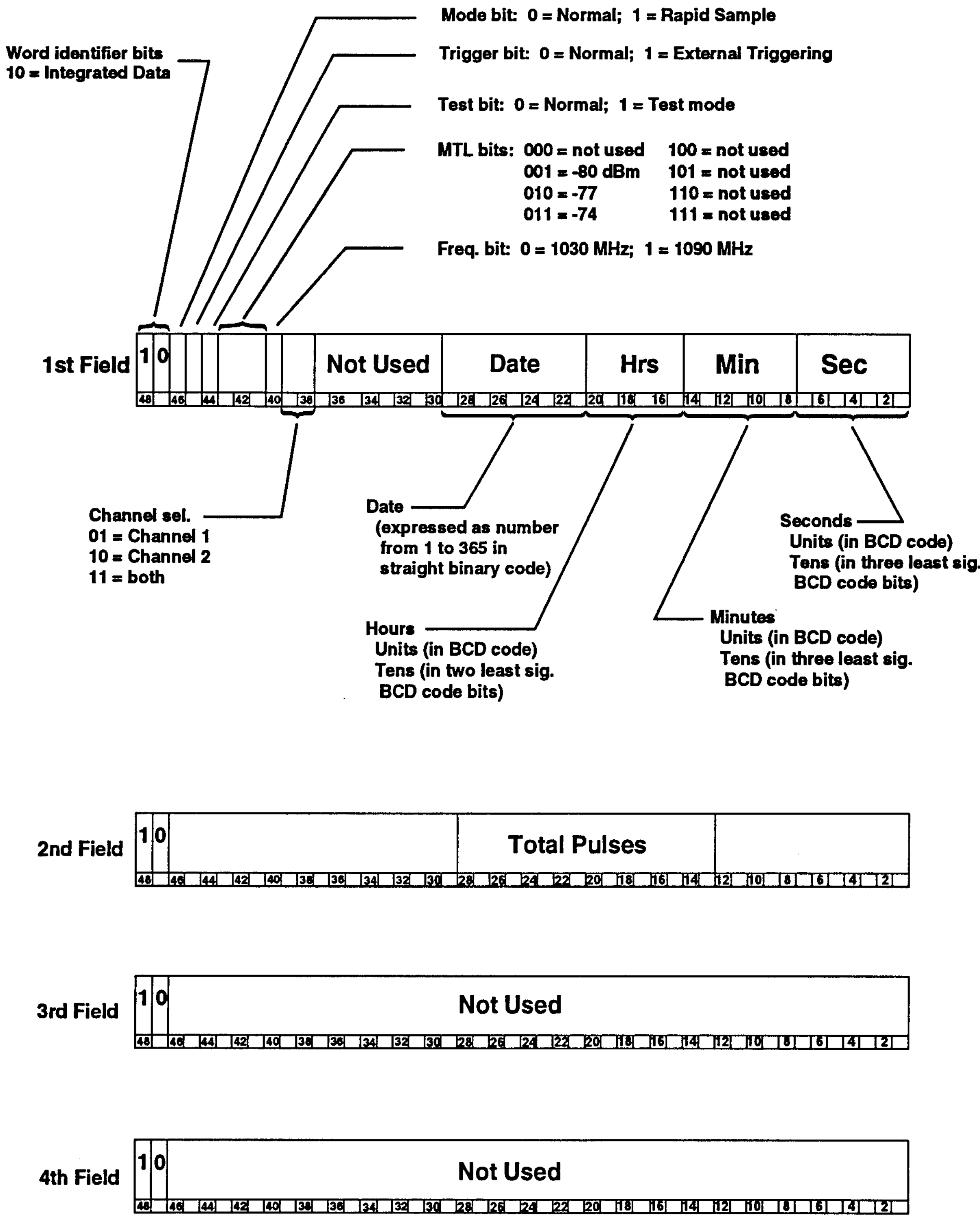

Figure A-3a. Format of Integrated Data Words.

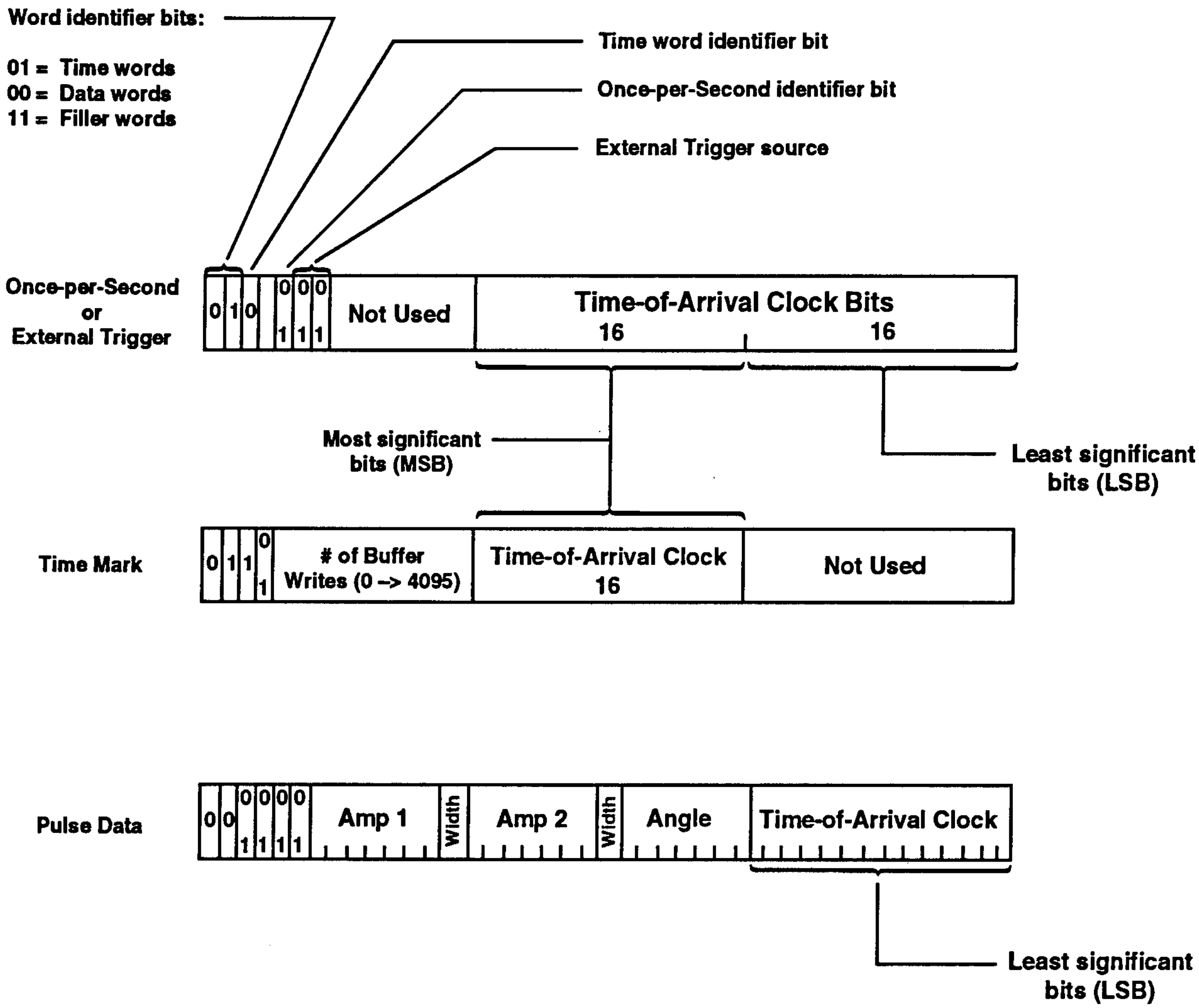

Figure A-3b. Format of Once-per-second, External Trigger, Time Mark, and Pulse Data Words.

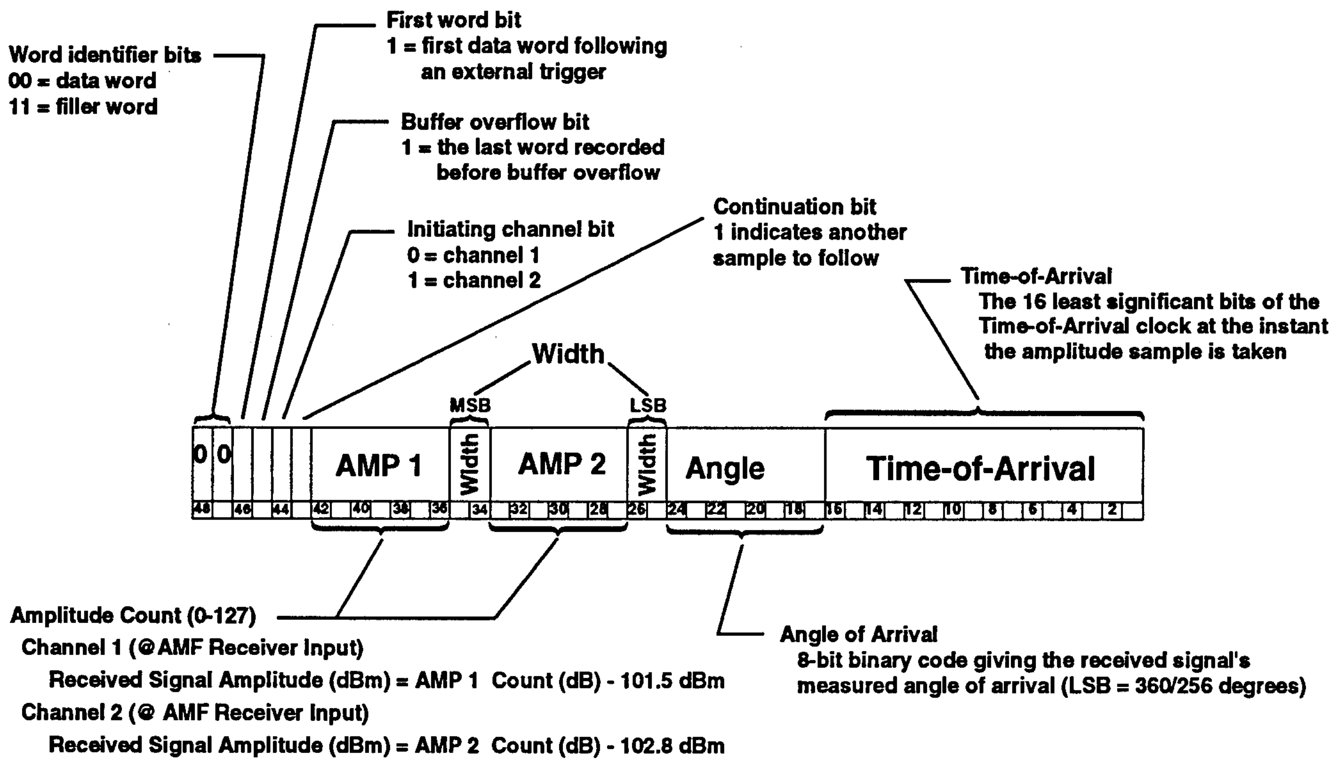

Figure A-3c. Pulse Data Word Format.

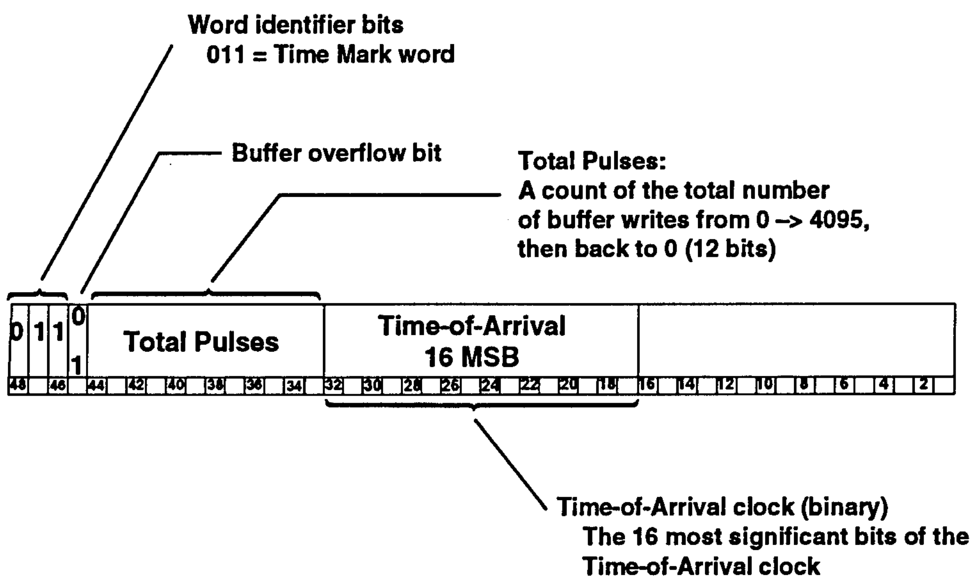

Figure A-3d. Time Mark Word Format.

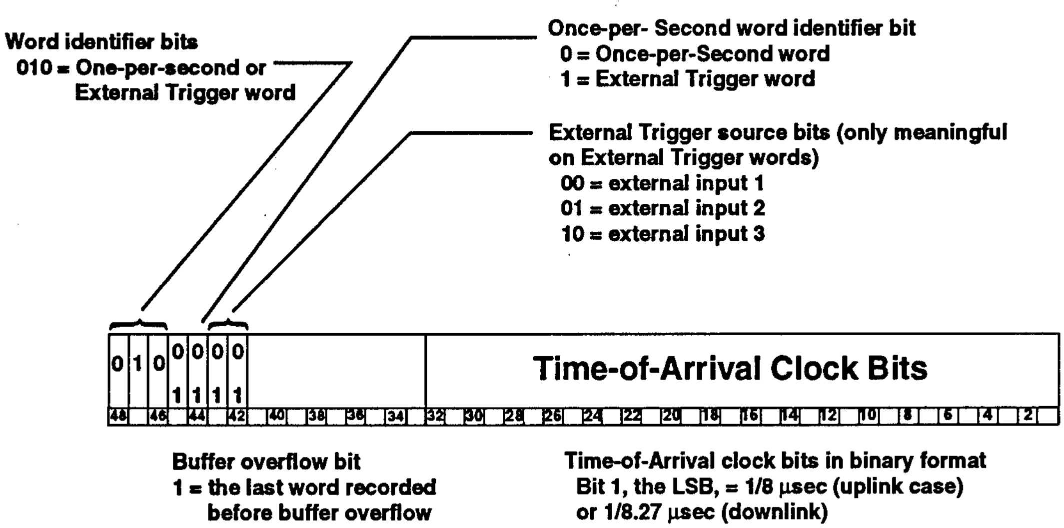

Figure A-3e. Once-per-Second or External Trigger Word Formats.

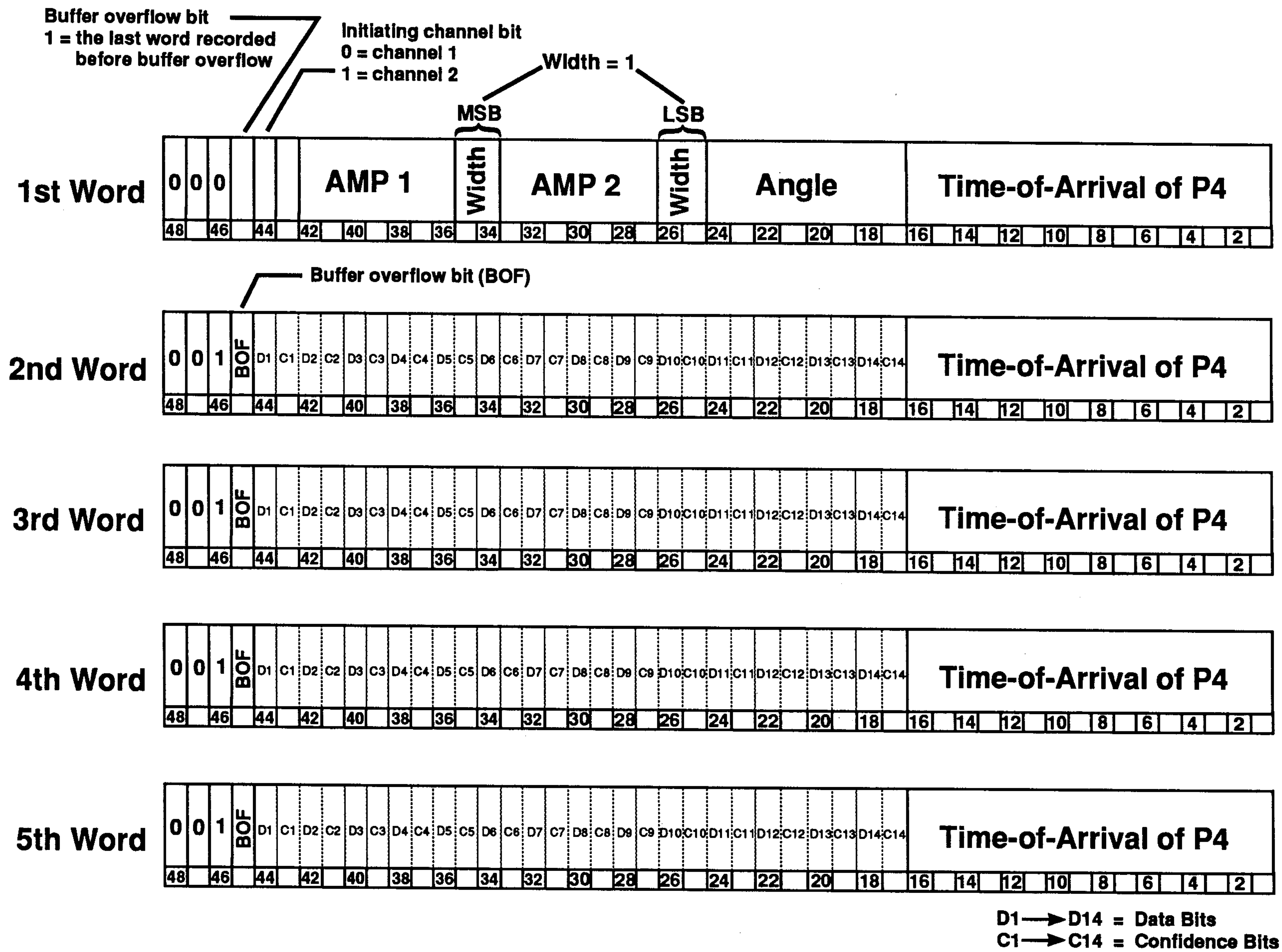

Figure A-3f. Format of Mode S Data Words.

APPENDIX B. REAL-TIME SOFTWARE TASKS

B.1 RECORD PROCESSOR

B.1.1 Record Processor Initialization Procedures

Under VxWorks, any C subroutine may be spawned as a separate task, with its own context and stack. Because many tasks use common resources in our application, the record processor software has been designed such that its tasks are responsible for initializing their own resources. This guarantees that each task will not access any common resources before they have been properly initialized. A real-time flag for initialization, referred to as an initialization semaphore, is the method used to perform all task initialization procedures. In contrast, initialization for the auxiliary processor resources is accomplished in an initialization routine. Table B-1 contains a listing of the Record Processor Software Tasks. Figure B-1 illustrates the AMF Auxiliary Processor Software Communication.

Table B-1. Record Processor Software Tasks

Task Name	**Function**
bsi4411Task	4411-board control task: This task controls the AMF data flow received from the 4411-board. It also handles the buffer full interrupts from the 4411-Board.
recctlTask	record control interface: • processes incoming data from all sources and manages the output tape ping-pong buffers. • creates and initializes the directory records.
tapeTask	tape control: • initializes the tape-drive. • receives buffer-full signal from recctlTask via a semaphore. • completes the directory records. • oversees output of data and directory information to the Exabyte tape. • informs the auxiliary processor of the memory location of pulse data records.
dmaTask	raw data input task: • receives signal to read in raw data from the 4411-board via an interrupt. • performs DMA controlled VMEbus transfer from the 4411-board into local memory.
4411Task	control the BSI 4411-board: • reads the initialization parameters corresponding to the 4411 configuration file. • controls operation of the 4411 board by reading/writing its registers and memory.
auxdataTask	auxiliary board data task: • receives data from the auxiliary processor via a socket and sends them to the recctlTask via a message queue.
auxcmdTask	auxiliary command Task: • sends commands to the auxiliary processor via a socket.
statusTask	status task: • receives and forwards status messages via a message queue from other tasks and forwards them to the SUN process via a socket.
playbackTask	oversee tape playback: • provides search capabilities for the tape playback tool. • sends commands to the Exabyte tape drive. • forwards data to the SUN process via a socket.
4416Task	control the BSI 4416 simulator board: • reads the initializing parameters from the 4416 configuration file. • controls operation of the 4416-board by reading/writing its registers and memory.
startTasks	initialization routine: • initializes system message queues. • spawns the other tasks under semaphore control.

B1.2 Task Priority Table for Record Processor

The VxWorks multitasking kernel uses interrupt-driven, priority-based task scheduling. Table B-2 provides a listing of the priority level that has been assigned to the record processor software tasks. The highest priority tasks are listed at the top of the table.

Table B-2. Task Priority

Task Name	Function and Priority Reasoning
bsi4411Task	4411-board control task: This task controls the AMF data flow received from the 4411-board. It also handles the buffer full interrupts from the 4411-Board.
dmaTask	DMA processing Task: This task empties the 4411 data buffer in a limited amount of time.
recctlTask	record control task: This task must process and direct all types of incoming data into the tape buffers.
tapeTask	tape interface task: This task is responsible for the rapid transfer of data from the tape ping-pong buffers to the tape drive.
auxdataTask	auxiliary board data task: This task receives and forwards data from the auxiliary processor to the tape buffers.
opctlTask & auxcmdTask	operator control tasks: These tasks handle commands issued by the user.
4416Task & playbackTask	remaining tasks: These tasks are not vital to the recording process so they are set to the lowest priorities

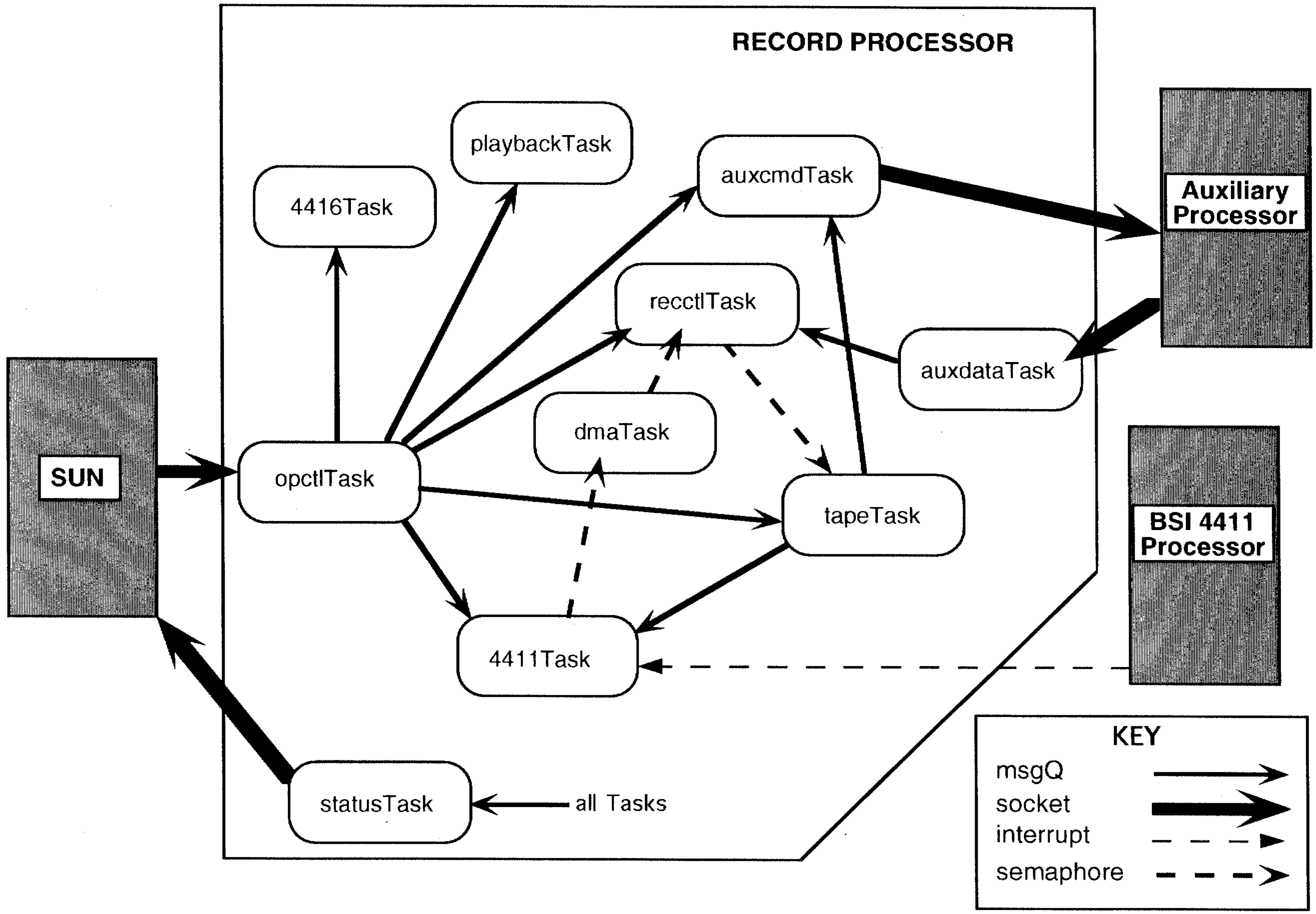

Figure B-1. AMF Record Processor Communication Channels.

B.1.3 Auxiliary Processor

Auxiliary Processor Initialization Procedures. Under VxWorks, any C subroutine may be spawned as a separate task, with its own context and stack. The initialization for the auxiliary processor resources is accomplished in a initialization routine. After initialization of the processor resources is complete, the initialization is responsible for spawning the auxiliary processor software tasks. Table B-3 contains a listing of the Auxiliary Processor Software Tasks. Figure B-2 illustrates the AMF Auxiliary Processor Software Communication.

Table B-3. Real-Time Auxiliary Processor Software Tasks

ctlTask	auxiliary board control: • receives commands from the record processor via a socket. • validates and sends commands to the appropriate task(s).
proc1Task	record processor interface: • receives and forwards data records from other tasks to the record processor via a socket.
gpsTask	GPS receiver task: • receives and forwards GPS information from the gpsRcvTask to the proc1Task. • provides the GPS time-of-day synchronization to the various processor clocks.
gpsRcvTask	GPS data receive task: • receives, decodes, and transmits GPS data from a serial port to the proc1Task.
altimeterTask	altimeter task: • receives, decodes and transmits altimeter data from a serial port to the proc1Task.
statusTask	receive status messages: • receives and forwards status messages from other tasks to the SUN process via a socket.
grabDataTask	real-time data process task: • oversees the real-time output of all types of data. • manages the data pointer lists and socket connections array. • processes the requests to obtain data. • sends the requested data (if available) via a socket to the SUN process.
arincTask	transponder data task main routine: • receives and transfers transponder data to the checkQTask. • initializes the VMIC ARINC board. • after receiving an interrupt, reads data from the VMIC board's memory. • decodes and sends the ARINC data to the checkQTask if data received is a TCAS broadcast.
tcasLivesTask	regular communication to transponder task: • sends messages to the transponder at regular intervals to ensure communication over the ARINC bus.
checkQTask	receive and transmit VMIC-board message task: • receives input from the tcasLives and ARINC tasks and writes data to the VMIC board when necessary.
aux_exec	auxiliary board initialization routine: • performs specific system-wide initialization. • spawns remaining auxiliary board tasks. • performs exiting software.

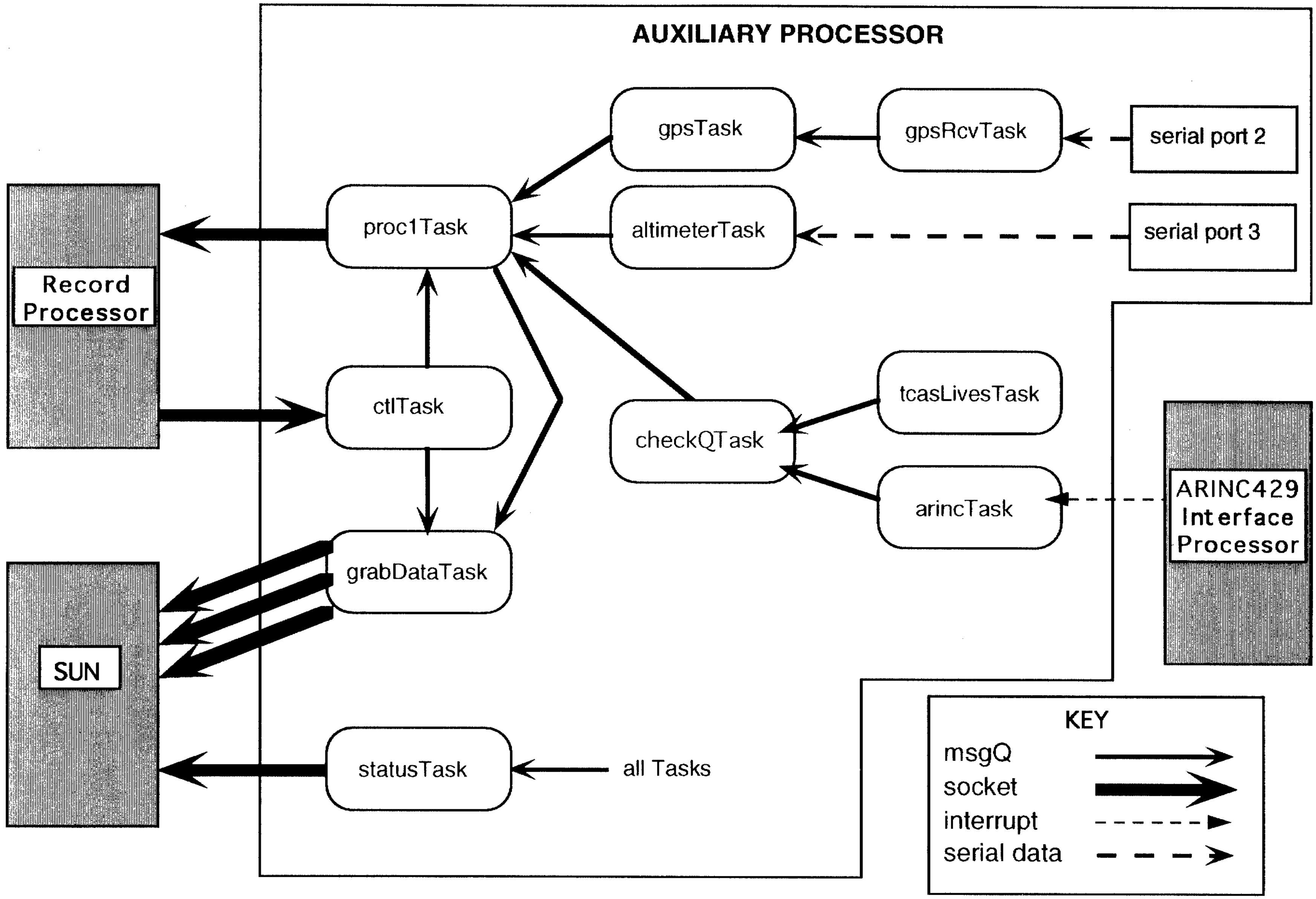

Figure B-2. AMF Auxiliary Processor Communication Channels.

B.1.3 Task Priority Table for Auxiliary Processor

The VxWorks multitasking kernel uses interrupt-driven, priority-based task scheduling. Table B-4 provides a listing of the priority level that has been assigned to the auxiliary processor software tasks. The highest priority tasks are listed at the top of the table.

Table B-4. Priority Level of Auxiliary Processor Software Tasks

Task(s)	Function and Priority Reasoning
Transponder/ARINC Tasks: arincTask tcasLivesTask checkQTask	transponder data process tasks: These tasks handle the processing of data received from the Mode S transponder. The ARINC protocol requires a quick response and handshake for each data transfer; thus, these tasks have been assigned the highest priority levels.
GPStasks: gpsTask gpsRcvTask	GPS data process tasks: These tasks process the GPS data.
altimeter task:	altimeter data process task: This task processes the altimeter data.
ctlTask	control task: This task handles commands received from the record processor.
proc1Task	record processor interface: This task sends data blocks to the record processor.
statusTask	receive status messages: This task forwards status messages to the SUN.
grabDataTask	real-time data process task: This task is not part of the recording process; thus is has been assigned the lowest priority level.

GLOSSARY

AMF	Airborne Measurement Facility
AMFRP	AMF Receiver Processor
ARINC	Aeronautical Radio, Inc.
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
FAA	Federal Aviation Administration
GPS	Global Positioning Satellite
GUI	Graphical User Interface
MTL	Minimum Triggering Level
Squitter	A spontaneous transmission broadcast once per second by Mode S transponders containing the address of the sender.
SSR	Secondary Surveillance Radar
TCAS	Traffic Alert and Collision Avoidance System
TOA	Time-of-Arrival
TOD	Time-of-Day
VME	Versa Module Eurocard

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